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Small hydropower for sustainable energy development in India

Himanshu Nautiyal[a,*], S.K. Singal[b], Varun[a], Aashish Sharma[a]

[a] Department of Mechanical Engineering, National Institute of Technology, Hamirpur, H.P., India
[b] Alternate Hydro Energy Center, Indian Institute of Technology, Roorkee, India

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ABSTRACT

Adequate amount of energy generation in a sustainable manner is a major challenge in the present energy scenario. Fast depleting fossils fuels and their environmental effects forces to look towards renewable sources for sustainable development. Among all renewable sources, small hydropower (SHP) is one of the promising sources for sustainable water and energy development. The geography of India supports the development of small hydro projects to enhance the energy generation. Small hydropower development is also necessary for proper utilization of available water resources. Present study has been carried out to highlight the water resource and small hydropower potential in India. Utilization of small hydropower sources for sustainable development has also been presented.

Contents

1. Introduction

Energy is required in each field of commercial and human activities. Energy generation is one of the major key factors for economic and social development in all the developed and developing nations of the world. The rapid economic growth demands more energy generation but the problem arises to provide desired amount of energy in a sustainable manner. In addition to this, there is a need to keep an eye on the environmental problems associated with extraction of energy from various resources. This is due to the fact that, the environmental degradation is being increased badly because of increase in pollution, population and industrialization. The problem of climate change has become a very critical issue due to the tremendous amount of green house gas (GHG) emissions. There is a sharp increase of GHG emissions in various nations except Russian Federation during 1992–2007 and is given in Table 1.

Fossils fuels like coal, petroleum are conventional sources of energy available in almost all countries, but their fast depletion, high prices and pollution problems forces to explore other clean and sustainable sources for energy generation. The pollution problems are also dangerous for the sustainability of human beings because pure air, water and other natural resources are essential requirements for a healthy and developed society. Therefore, solutions to environmental problems are important for sustainable development. The possibility of human sustainability is in following of natural laws of mass and energy balance [2]. The human sustainability depends on the well being of natural resources. Fig. 1 shows that balance is must in interaction of a human being with technology, economic growth, environment and resources.

The use of renewable sources is the most valuable solutions to reduce the environmental problems associated with fossil fuels based energy generation and achieve clean and sustainable energy development. Hydro, wind, biomass, solar and geothermal is important renewable sources for energy generation. All the nations

* Corresponding author.
E-mail address: h2nautiyal@gmail.com (H. Nautiyal).

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Table 1
Change in GHG emissions during (1992–2007) [1].

Sno.	Country	Change in GHG emissions (%)
1	China	+150
2	India	+103
3	United States	+20
4	Japan	+11
5	Russian Federation	−20
6	Worldwide Total	+38

of the world are shifting their focus to extract energy from the renewable sources. Table 2 shows the list of top ten renewable electricity producer nations of the world.

The renewable energy sources can be ranked on the basis of several critical sustainability indicators like price of generated electricity, green house gas (GHG) emissions, availability of source, efficiency of energy conversion, land acquisition and social impacts [7]. Among all renewable sources, hydropower is a clean and common source, providing about 88% of the world's electric power [8]. Hydropower generation is carried out on large and small scale throughout the world. But problems like high capital cost, rehabilitation, resettlement of people, geographical disturbance are associated with large hydropower projects.

Small hydropower (SHP) is an appropriate answer to all the drawbacks of large hydro power projects. An assessment of renewable based energy generation technologies against the indicators viz. cost of electricity generation, GHG emissions and energy payback time (EPBT) concluded that small hydro is a well utilizable source for the sustainable development [9]. Also a study of two major electric system of Chile concluded that small hydro is an economically viable source even without an introduction of policy measures [10]. Initially, this technology was specifically used in water wheels for rice hulling, milling of grain and other mechanical applications. But it has become an efficient source for energy generation. The small hydro energy generation is environment friendly and it is very useful for generating the electricity in rural and urban areas. SHP projects are established on canals, dam and run-of river sites. The problem of unelectrified remote and isolated areas can be solved by establishing small hydro projects. As compared to the other electricity generation systems, the energy payback time (EPBT) and GHG emissions in SHP generation system are less [11]. Apart from this, small hydro projects are also installed at the tail ends of cooling water systems of thermal power plants. This is an example of energy conservation through small hydro. India has a good geographical location with small and big water resources in abundance. Small hydro development is an important step for conservation of water resources and sustainable development in India. The possibilities and scope of enhancement of SHP in India was attempted to explore in the present study.

Fig. 1. Interaction of human being with its surroundings.

Table 3
Water resources in India.

Sno.	Items	Quantity (km^3)
1	Annual precipitation (including snowfall)	4000
2	Average annual availability (2001) in cubic meter	1869
3	Per capita water availability	1820
4	Estimated utilizable water resources	1123
	(i) Surface water resources	690
	(ii) Ground water resources	433

2. Water potential in India

The annual precipitation in India is estimated as 4000 km^3 and the potential of resources as natural run off in the rivers is approximately 1869 km^3 but due to topographic constraints only 1123 km^3 of total potential is utilizable [12]. Table 3 shows the Indian water resources at a glance.

The rain fall during November to February from North-East monsoon and June to September from South-West monsoon helps to maintain the ground water level. Rivers are the major surface water resources in India. The country has many monsoon-fed, double monsoon-fed, snow-fed and small water streams. Various rivers flow in Himalayan, peninsular, coastal, and inland drainage basin areas. The total area covered by the Himalayas is about 600,000 km^2 and nineteen major rivers rise among the mountains. Himalayan rivers maintain a high to medium rate of flow throughout the year. The heavy rain falls in Himalayan regions increases the flow of the rivers. The flow of water in peninsular rivers is also increased during the rainy seasons but the coastal rivers highly depend on season.

Table 2
World's top 10 renewable electricity producer nations (units in TWh) [3–6].

Rank	Country	Hydro power	Wind power	Biomass	Solar	Geo thermal	Other sources[a]	Total
1	China	563.3	12.8	3	0.14	–	–	576.1
2	Brazil	371.5	0.6	14.3	–	–	–	385.8
3	United States	250.8	52.0	55.4	0.596	16.778	-	375.6
4	Canada	368.2	1.471	–	0.017	–	–	369.7
5	Russia	174.604	0.007	–	–	–	0.41	179.1
6	Norway	136.572	0.506	0.2	–	–	–	137.3
7	India	122.4	14.7	–	–	–	–	137.1
8	Japan	86.350	1.754	–	0.002	3.027	–	95.0
9	Venezuela	83.9	–	–	–	–	-	83.9
10	Germany	26.717	38.5		3.5	–	–	68.7

[a] Other sources include wave energy and waste-to-energy.

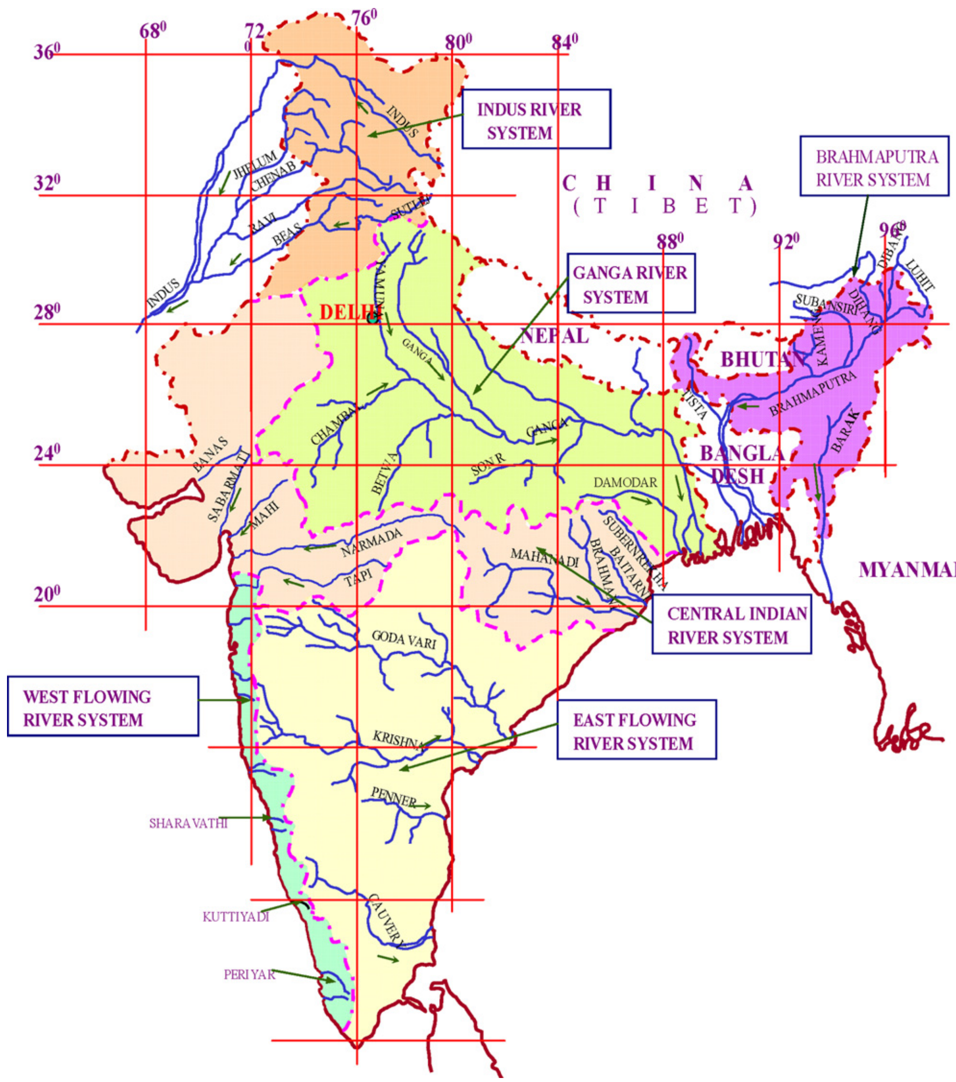

Fig. 2. Major river systems of India.

The inland drainage basin rivers are few and frequently disappear in deficient rainfall. Classification of rivers of India with their catchment area is shown in Tables 4–7. The rivers of India are shown in Fig. 2.

Table 4
Major rivers of India and their catchment areas [13].

Sno.	Name of the river	Length (km)	Catchment area (sq. km.)
1	Indus[a]	1114	321,289
2	Ganga[a]	2525	861,404
3	Brahmaputra[a]	916	194,413
4	Barak	–	41,723
5	Sabarmati	371	21,674
6	Mahi	583	34,842
7	Narmada	1312	98,796
8	Tapi	724	65,145
9	Brahmani	799	39,033
10	Mahanadi	851	141,589
11	Godavari	1465	312,812
12	Krishna	1401	258,948
13	Pennar	597	55,213
14	Cauvery	800	87,900
	Total		2,534,781

[a] In India.

In addition to these, the big natural lakes like Kolleru (Andhra Pradesh), Wullar (Jammu and Kashmir), Chilka (Orissa), Pulikat (Tamil Nadu), Vembanad (Kerala) are also important surface water resources in India. Wetlands like Bhittarkanika (Orissa), Bhoj (Madhya Pradesh) further increase the surface water potential of India.

The major and medium hydropower projects contribute total storage capacity of 174 km^3 and projects under implementation will further contribute 75 km^3 to the above capacity. Major states of India (Andhra Pradesh, Karnataka, Madhya Pradesh, and Uttar Pradesh) contribute more than 71% of the total live storage capacity [14]. In view of the above data, proper utilization of the water resources in the form of electricity generation, irrigation, drinking water and other domenstic needs is necessary for sustainable development. Small hydropower development is very important for harnessing the power in sustainable manner from these plenty of water resources as presented in the study.

3. Small hydro power as a sustainable energy source

SHP projects can be installed in rivers, small streams, dams and canals with negligible apparent environmental effects. In order to minimize the environmental effects and maximize water conservation, prominence has been given to the development and integration of SHP projects into river systems during last few years [8].

Table 5
Medium rivers of India and their catchment areas [13].

Sno.	Name of the river	Length (km.)	Catchment area (sq. km.)
1	Ozat	128	3189
2	Shetrunji	182	5514
3	Bhadar	198	7094
4	Aji	106	2139
5	Dhadar	135	2770
6	Purna	142	2431
7	Ambika	142	2715
8	Vaitarna	171	3637
9	Damanganga	143	2357
10	Ulhas	145	3864
11	Savitri	99	2899
12	Sastri	64	2174
13	Washishthi	48	2239
14	Mandavi	87	2032
15	Kali Nadi	153	5179
16	Gangawati or Bedti	152	3902
17	Sharavati	122	2209
18	Netravati	103	3657
19	Chaliar or Baypore	169	2788
20	Bharathapuzha (Ponnani)	209	6186
21	Periyar	244	5398
22	Pamba	176	2235
23	Burhabalang	164	4837
24	Baitrani	365	12,789
25	Rushikulya	146	7753
26	Vamsadhara	221	10,830
27	Nagavali	217	9410
28	Sarda	104	2725
29	Yeleru	125	3809
30	Gundlakamma	220	8494
31	Musi	112	2219
32	Paleru	104	2483
33	Muneru	122	3734
34	Swarnamukhi	130	3225
35	Kandleru	73	3534
36	Kortalaiyar	131	3521
37	Palar (including Cheyyar)	348	17,871
38	Varsha Nadi	94	3044
39	Ponniar	396	14,130
40	Vellar	193	8558
41	Vaigai	258	7031
42	Pambar	125	3104
43	Gundar	146	5647
44	Vaippar	130	5288
45	Tambrsparmi	130	5969
46	Subarnarekha	395	19,296
	Total		2,45,909

Small hydropower is a key element for sustainable development due to the following reasons:

- *Proper utilization of water resources*: Various streams and rivers can safely provide energy to run a small hydro electric plant. No big water storage is required in such projects which prevents resettlement and rehabilitation of the population.

Table 6
Catchment areas of minor rivers [13].

Sno.	State	Catchment area (Sq. km.)
1	Gujarat	4634
2	Karnataka	2146
3	Goa	2102
4	Kerala	10,489
5	West Bengal	10,000
6	Andhra Pradesh	44,142
7	Tamil Nadu	21,270
8	Maharashtra	15,510
	Total	110,293

Table 7
Desert rivers and their catchment areas [13].

Sno.	Name of the river	Catchment area (sq. km.)
1	Luni and others	80,000
2	Machhu	2515
3	Rupen	4000
4	Saraswati	2935
5	Banas	8674
6	Ghaggar	1309
	Total	99,433

- *Small hydro power is a renewable source of energy*: Small hydropower meets the definition of renewable because it uses the energy of flowing water repeatedly generates electricity without fear of depletion to.
- *Small hydro is a cost effective and sustainable source of energy*: Simple and less expensive construction work and in expensive equipment are required to establish and operate small hydropower projects. The cost of electricity generation is inflation free. Also, the gestation period is short and the schemes give financial returns quickly.
- *Small hydro aids in conserving scarce fossils fuels:* No fossils fuels and other petroleum products are required in small hydro electric project. SHP replaces the fossil – fired generation of electricity.
- *Clean and non-polluting source:* SHP projects are known for low carbon energy production. Small hydro is a pollution free source for electricity generation and environment problems like GHG emissions, acid rain are not associated with it. The development of small hydro has low effect on the environment. In small hydro, no big storage is formed and rehabilitation of population is not required as in case of large hydropower projects.
- *Development of rural and remote areas*: In remote and hilly areas, sources for development of small hydro are found in abundance. Small hydro development provides electricity, transportation, communication links and economy to such rural areas.
- *Other uses*: Small hydropower also gives additional benefits along with power generation such as irrigation, water supply, flood prevention, fisheries and tourism.

4. Small hydro power potential in India

In India, hydro power projects up to 25 MW are classified as small hydro projects. The estimated small hydro power potential in India is around 15,000 MW. Of this estimated potential only 16% has been developed so far for power generation [15]. Table 8 shows an overview of small hydro potential and development in India.

In India, 5415 sites with a capacity of 14,305.47 MW have been identified by Ministry of New and Renewable Energy (MNRE) for establishment of small hydroelectric projects. The largest numbers of sites have been identified in Arunachal Pradesh with total capacity of 1333.04 MW but the richest state in SHP potential is Himachal Pradesh with 547 sites of total capacity of 2268.41 MW. The identified SHP potential sites with total capacity of different states of India are shown in Table 9. The statistics of Table 9 shows

Table 8
Small hydro in India [15].

1	Estimated potential	15000 MW
2	Identified potential	14,305.47 MW
3	Installed capacity	2429.77 MW
4	Capacity under implementation	483.23 MW
5	Identified sites	5415
6	No. of small hydro projects (installed and under implementation)	863
7	No. of installed small hydro projects	674
8	No. of small hydro projects under implementation	188

Table 9
State wise identified sites with capacity up to 25 MW (as on 31.3.2009) [15].

Sno.	State	Identified site	Total capacity (MW)
1	Andhra Pradesh	489	552.29
2	Arunachal Pradesh[a]	566	1333.04
3	Assam[a]	60	213.84
4	Bihar[a]	94	213.75
5	Chhattisgarh	164	706.62
6	Goa	9	9.10
7	Gujarat	292	196.97
8	Haryana	33	110.05
9	Himachal Pradesh[a]	547	2268.41
10	Jammu & Kashmir[a]	246	1411.72
11	Jharkhand	103	208.95
12	Karnataka	128	643.16
13	Kerala	247	708.10
14	Madhya Pradesh	99	400.58
15	Maharashtra	253	762.58
16	Manipur[a]	113	109.10
17	Meghalaya[a]	102	229.81
18	Mizoram[a]	75	166.94
19	Nagaland[a]	99	196.98
20	Orissa	222	295.47
21	Punjab	234	390.02
22	Rajasthan	67	63.17
23	Sikkim[a]	91	265.54
24	Tamil Nadu	176	499.31
25	Tripura[a]	13	46.86
26	Uttar Pradesh[a]	220	292.16
27	Uttaranchal[a]	458	1609.25
28	West Bengal[a]	203	393.79
29	A&N Island	12	7.91
	Total	5415	14,305.47

[a] Himalayan states.

Table 11
State wise SHP projects installed in private sector (as on 31.3.2009) [15].

Sno.	State	Total number	Total capacity (MW)
1	Andhra Pradesh	41	96.93
2	Assam	1	0.10
3	Himachal Pradesh	33	134.45
4	Karnataka	66	520.80
5	Kerala	2	33.00
6	Madhya Pradesh	1	2.20
7	Maharashtra	4	21.00
8	Orissa	1	12.00
9	Punjab	10	16.65
10	Tamil Nadu	1	0.35
11	Uttaranchal	9	43.30
12	West Bengal	5	6.45
	Total	174	887.23

that 14 Himalayan states of India have small hydro potential of 7551.19 MW. These Himalayan states are more suitable for development of small hydro projects.

5. Development of small hydropower in India

India's first SHP project of 130 kW was commissioned in Darjeeling, West Bengal in 1897. Then, In 1902 Sivasamudram project was started in Mysore, Karnataka to supply power to the Kolar gold mines [16]. After this, more plants such as Galogi in Mussoorie, Uttarakhand (1907), Chaba in Himachal Pradesh (1914) were established. After independence in 1947, fast development in the field of power generation was required. So, importance was given to the development of thermal and big hydro power plants for increasing the generation of electricity. Due to this, the development of small hydro projects was slow. But during the last two decades, the need for development of small hydro projects has been arisen again due to increase in prices of fossil fuels and environmental

Table 10
State wise SHP projects (up to 25 MW) installed and under implementation (as on 31.3.2009) [15].

Sno.	State	Projects installed		Projects under implementation	
		Nos.	Capacity (MW)	Nos.	Capacity (MW)
1	Andhra Pradesh	59	180.83	12	21.50
2	Arunachal Pradesh	81	61.32	43	25.94
3	Assam	4	27.1	4	15.00
4	Bihar	12	54.60	4	3.40
5	Chhattisgarh	5	18.050	1	1.00
6	Goa	1	0.050	–	–
7	Gujarat	2	7.000	2	5.60
8	Haryana	5	62.700	1	6.00
9	Himachal Pradesh	79	230.915	9	26.75
10	J&K	32	111.830	5	5.91
11	Jharkhand	6	4.050	8	34.85
12	Karnataka	83	563.45	14	85.25
13	Kerala	19	133.87	2	3.2
14	Madhya Pradesh	10	71.16	4	19.90
15	Maharashtra	29	211.325	5	31.20
16	Manipur	8	5.450	3	2.75
17	Meghalaya	4	31.030	3	1.70
18	Mizoram	18	24.470	1	8.50
19	Nagaland	10	28.670	4	4.20
20	Orissa	8	44.300	6	23.93
21	Punjab	29	123.900	2	18.75
22	Rajasthan	10	23.850	–	–
23	Sikkim	16	47.110	2	5.20
24	Tamil Nadu	15	90.050	4	13.00
25	Tripura	3	16.010	–	–
26	Uttar Pradesh	9	25.100	–	–
27	Uttarakhand	93	127.92	33	40.35
28	West Bengal	23	98.400	16	79.25
29	A&N Islands	1	5.250	–	–
	Total	674	2429.77	188	483.23

Table 12
State policies for private sectors small hydro power projects [15].

S. No.	State	Wheeling	Banking	Third party sale	Annual escalation
1.	Andhra Pradesh	2% of energy generated	2%; 8–12 months	Allowed	Nil
2	Arunachal Pradesh	Allowed charges to be determined by SERC	With prior permission of State Govt.	Permitted	Nil
3	Assam	As decided by AERC for TP; no charges for sale to ASEB	For 6 months	Permitted	Nil
4	Bihar	Allowed, terms to be decided by BSEB		Permitted	Nil
5	Chhattisgarh	To be decided by CSEB		Permitted	Nil
6	Gujarat	4% of energy generated	For 6 months		Nil
7	Haryana	2% of energy generated	Allowed	Permitted	5%
8	Himachal Pradesh	2% of energy generated	Allowed with additional charges	Not permitted	Nil
9	Jammu and Kashmir	10% now, to be decided by SCRC. No charges for sale to PDD or local grid	Allowed for 2 months	Permitted HT consumers	Nil

SERC: State Electricity Regulatory Commission, AERC: Assam Electricity Regulatory Commission, ASEB: Assam State Electricity Board, BSEB: Bihar State Electricity Board, CSEB: Chhattisgarh State Electricity Board, PDD: Power Development Department, TP: Third Party Sale.

degradation through thermal power projects. In 1992, Ministry of Non Conventional Energy Sources (Now renamed as Ministry of New and Renewable Energy (MNRE)) was formed by Government of India for development of energy generation through clean and economic renewable sources of energy. After this, development of SHP projects acquired good pace. Now, new potential sites are being identified by MNRE for establishment of small hydro projects. Stand alone systems are being used for decentralized electricity generation in remote and hilly areas with full cooperation of local communities and different Non Government Organisations (NGOs). The involvement of private sector agencies in SHP projects is a bench mark for development of small hydro in India. The installed and under implemented SHP projects in different states in India are listed in Table 10.

6. Government policies and private sector initiatives for SHP development in India

India is planning to increase power generation from SHP projects to 7000 MW by the end of 12th five year plan (2017). The nodel Ministry, MNRE aims that out of the total grid interactive power generation capacity that is being installed, 2% should come from small hydro. The Indian Government is also providing financial support to government as well as private developers for identifying and developing new SHP sites, grid interactive and decentralized projects. Guidelines and various parameters have been defined by the Government to work out tariff for electric generation through SHP. Soft loans are provided to small hydro projects through government financial institutions such as Indian Renewable Energy Development Agency (IREDA), Power Finance Corporation (PFC) and Rural Electrification Corporation (REC). Hydropower Corporations of central and various state governments, the power generating companies are trying to increase power generation by developing small hydropower plants.

Government of India provides financial subsidy to power generating companies in public/private sector and NGO's for establishing new, renovation, modernization and up rating of small hydro plants. Government monitors the progress of development to ensure the proper utilisation of subsidy. The subsidy is given in installments to public sector companies and on completion to private sector companies. The final installment of subsidy is released on submission of performance testing report after successful commissioning of the plant. Alternate Hydro Energy Centre (AHEC) at Indian Institute of Technology, Roorkee has been designated as the agency responsible for carrying out such performance related test. The participation of private sector for development of SHP projects has been encouraged by Government of India due to which 174 SHP projects have been installed in private sector (see Table 11).

India is union of states and there is a division of executive and legislative powers between the Indian Union (Central government) and the states. Hydro power is a state subject and interstate rivers are dealt by central government. Hence for hydro power development both the central and state governments are involved. Out of twenty nine states, twenty three states of India viz. Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Mizoram, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttarakhand, Uttar Pradesh and West Bengal have developed policies for establishing SHP projects through private sector companies. Table 12 shows policies for private sectors small hydro projects.

7. Conclusions

Problems like environmental hazards, GHG emissions, and pollutions are associated with fossil fuel based energy generation. Due to this, the necessity of energy generation by renewable sources needs to be increased for sustainable development. Among all renewable sources, small hydro is a clean and well utilizable source of energy. SHP projects are very useful for providing electricity to remote and rural areas. Water conservation and other benefits like irrigation, water supply, flood prevention, fisheries and tourism further increases the benefits of small hydro projects and make it self sustainable. The total small hydro potential of India is 15000 MW, but only 16% of this potential has been developed for the power generation. The initiatives of the Government are appreciable for increasing new establishment of SHP projects in small hydro sector throughout the country.

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